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Stripline Directional Coupler for 400 MHz to 3.6 GHz

I was preparing to move to new accommodation, and I began to think about extending my measuring equipment. You can buy many things, but good directional couplers are very expensive, assuming you can get them at all. Normal λ/4 microstrip couplers are frequently used, but their directivity effect is nothing special; and they are certainly not broad-band.

1. BASIC FACTORS

In my search for a solution I found a comprehensive description of directional couplers in the book "Stripline Circuit Design" by Harlan Howe [1]. Why Stripline (Triplate)? It very quickly became apparent that Stripline has marked advantages, as against Microstrip, in relation to the directivity. A directional coupler which consists only of 2 λ/4 long coupled lines has a band width of one octave. If this coupler is extended by additional λ/4 couplers with an expanded interaction gap (Fig.1), the usable frequency range is expanded. At n = 3, we can already obtain a band width of 4:1 to 8:1 - depending on the permitted ripple, of course. If we want a coupler with a band width exceeding 9:1, we have to use a structure with n ≥ 4. The consequence is that the coupler becomes very long and this also means the losses in the substrate increase.

Another option is to use an asymmetrical structure. This saves us almost half the λ/4 segments required - with scarcely any deterioration in the characteristics (Fig.2).

For a symmetrical coupler, the phase displacement to the de-coupled port is always 90°.

For an asymmetrical coupler, the phase displacement is frequency-dependent, but this is irrelevant for amateur radio applications.

One question troubled me here. Are there differences between the 2/4 coupling and the 1/3? Simulations show that

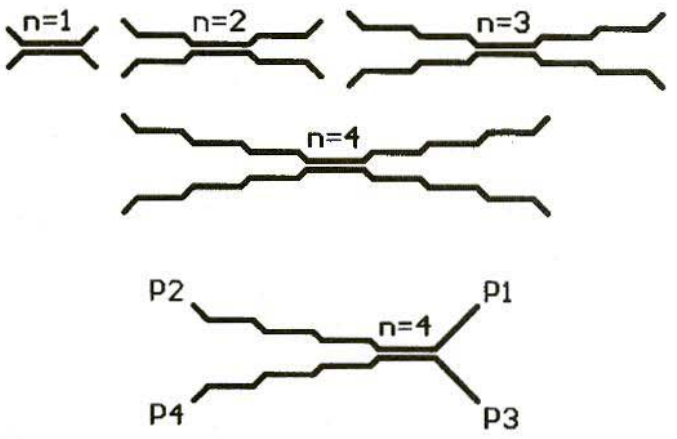

Fig.1: Symmetrical and Asymmetrical Couplers

the coupling for the 2/4 port is more strongly frequency-dependent than that for the 1/3 port. The reason for this is the transmission loss through the segments right up to the λ/4 segment, limiting for the high frequencies, with the smallest coupling gap.

2. REALISATION

Once these basic principles were clear, the original problem could also be solved very quickly. The result was a symmetrical coupler with n = 3 on Rogers RO3003 material.

Since this solution is very expensive, because of the base material used, the idea of a version which would give better value was pursued. So how well suited, or how badly suited, is FR4 epoxy material to these high frequencies?

I discovered through simulation, using Super-Compact, that, with limitations, a "normal" assembly could be carried out right up to 3.5 GHz. As a result of the simulation, I expanded the original structure (n = 4) by one λ/4 segment.

The useful frequency range goes from

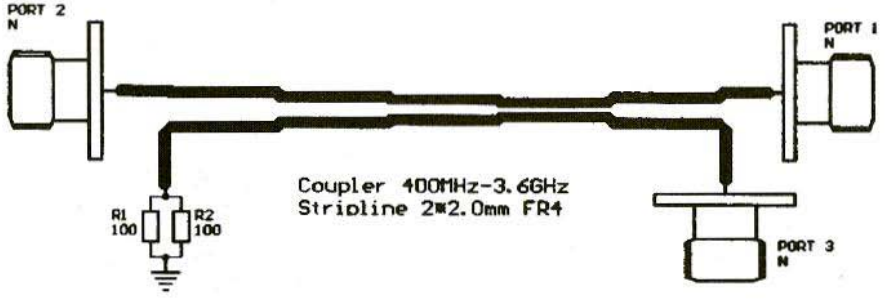

Fig.2: Wiring Diagram of Asymmetrical Stripline Coupler

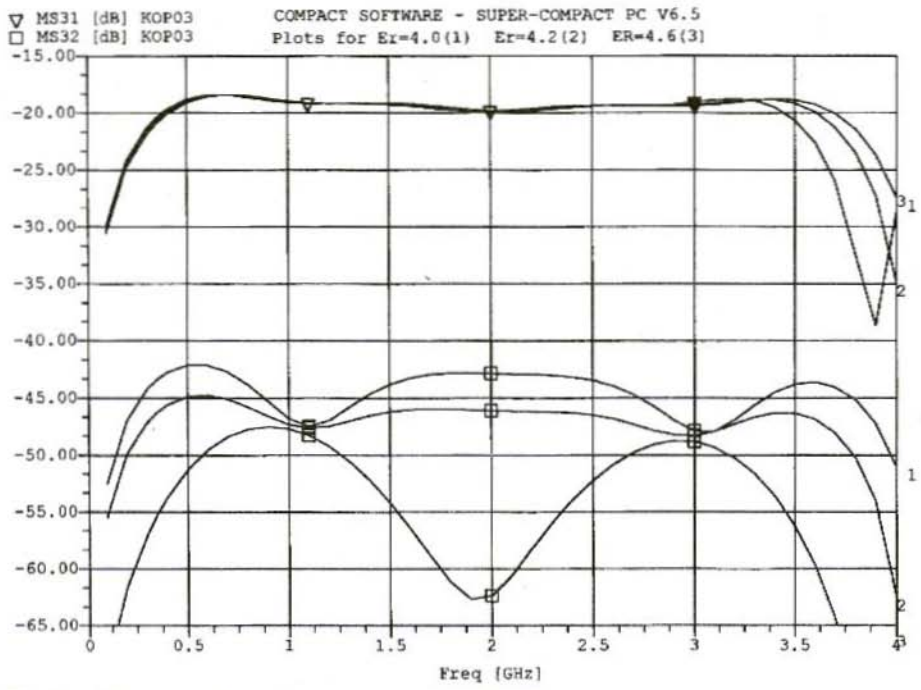

Fig.3: Simulation Results for Coupling and Directivity for various values of ε_r

400 MHz to 3.5 GHz at 20 ±1dB coupling.

The biggest disadvantage of FR4 is the attenuation, which here reaches a = 1.5dB at 3.5 GHz, and is thus close to maximum. A certain amount of uncertainty comes from the ε_r, which oscillates, depending on the manufacturer, between ε_r = 4.0 and 4.6. In my simulations, I use a value of ε_r = 4.2 for FR4. The effects are displayed mainly by the fact that the operating range of the coupler is displaced (Fig.3).

2.0 mm. was selected as the thickness of each substrate. The Triplate was reinforced by a 2 mm. thick aluminium plate to give sufficient mechanical stability.

2 x 100Ω SMD 0805 resistors were integrated into the Triplate between two 2.0 mm. thick epoxy printed circuit boards. In order to obtain enough room for the resistors, some epoxy had to be "carved out" of the second board. The important thing here was that the earth contact for the resistors was soldered to all 3 layers with 2 pieces of wire (0.8 mm. long). You should also make sure that there is a good contact between the screws and the two earth surfaces (Fig.4).

In a reflection measurement, the two chip resistors, which added up to 0.25 W, limited the preliminary power to 25 Watts.

Fig's.5 and 6 show the structure of the coupler.

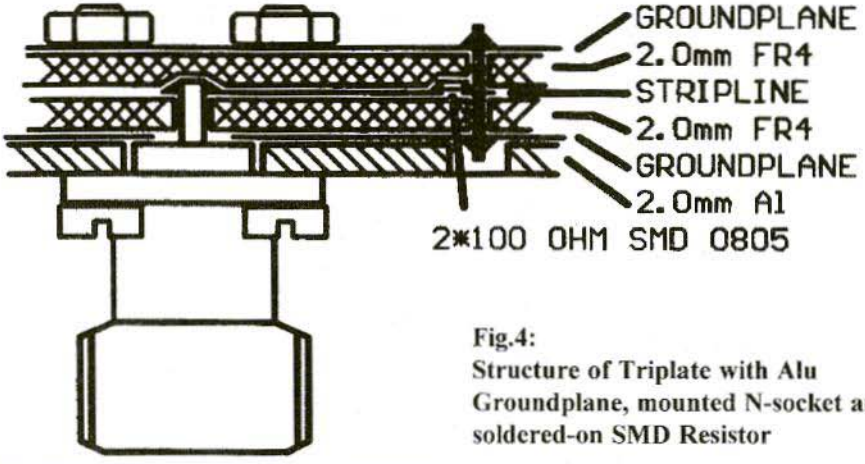

Fig.4:
Structure of Triplate with Alu Groundplane, mounted N-socket and soldered-on SMD Resistor

3. UNEXPECTED OBSTACLES

You can calculate everything on the coupler beautifully, use a high-quality substrate and have a good seal, and still not obtain good directivity. The reason for this is usually the sockets used. These components, or the way they are matched, have or has a direct influence on the directivity. The best solution is to use special sockets for striplines with "pennants" as centre contacts (e.g. from Rosenberger).

As I had no such N-sockets available during assembly, I tried my luck with "normal" N-sockets, which possess a thinner dielectric (d = 5.8 mm.) on the flange side.

After completing the coupler I had to admit that the return loss with this socket was still only R_L = - 22dB at 2.4 GHz.

The reason for this is that this socket has a section about 2 mm. longer with only 45Ω. Another type of socket was even worse. It had an area 5 mm. long with an impedance of only 40 Ω.

To get things clear in my mind, I sawed the sockets down and tested them on the spot.

4. MEASUREMENT RESULTS

No matter how attractive the simulation results may have been, the measurement results (Fig's.7, 8) for the prototypes looked completely different. However, this was mainly in relation to the return loss, which at times was only 14dB (Fig.9).

The reason for this lay in the sockets, or in the way they were mounted.

In this case, however, I laid greater emphasis on a simple, mechanically solid construction which, for example, did not immediately collapse when two Aircom cables were connected.

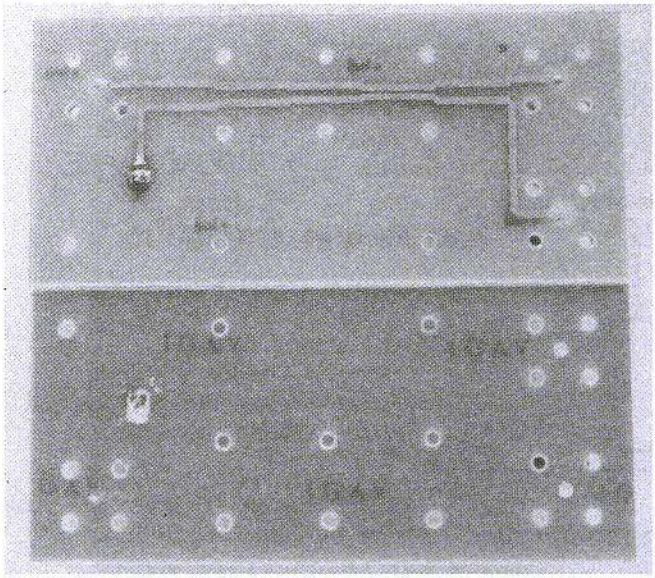

Fig.5: Structure of Coupler: Printed Circuit Board before Assembly

5. MAKING YOUR OWN

For those who want to start making their own version straight away, here are the dimensions for a coupler, with n = 5, mounted on 2 x 1.5 mm. FR4 epoxy (Fig.10).

Since there will certainly be no problem with access to programs for the design of printed circuit boards, I am giving only the dimensions here.

- All lines lie on a 5 mil (0.005°) basic grid.
- The printed circuit boards are always 56 mil wide, and the length of a coupler segment is 690 mil.
- The length of the entire coupler is app. 88 mm. and thus fits crosswise onto a Euro-card.

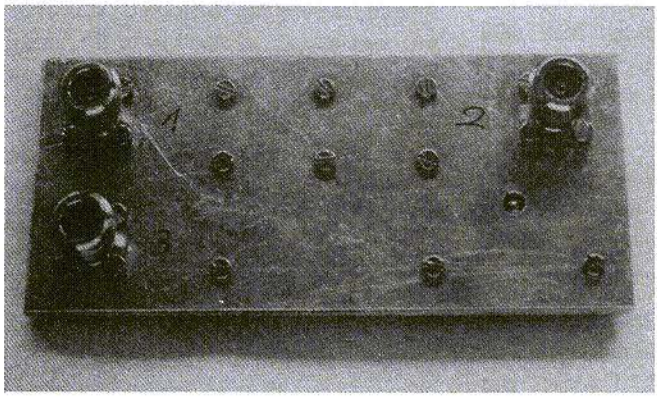

Fig.6: View of Prototypes with N-sockets

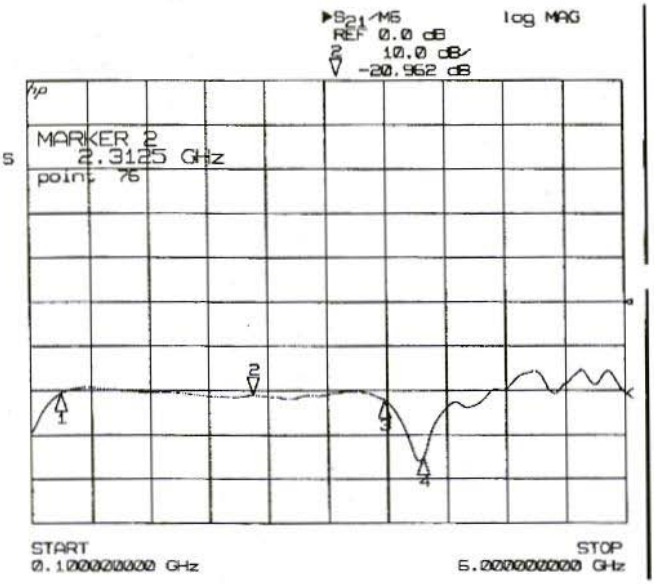

Fig.7: Measurement Diagram for Coupling Port 1 to 3:

400 MHz - 3 GHz = 20 ± 1dB;

Marker 1: 400 MHz,

Marker 2: 2.31 GHz,

Marker 3: 3.6 GHz,

Marker 4: 4.0 GHz

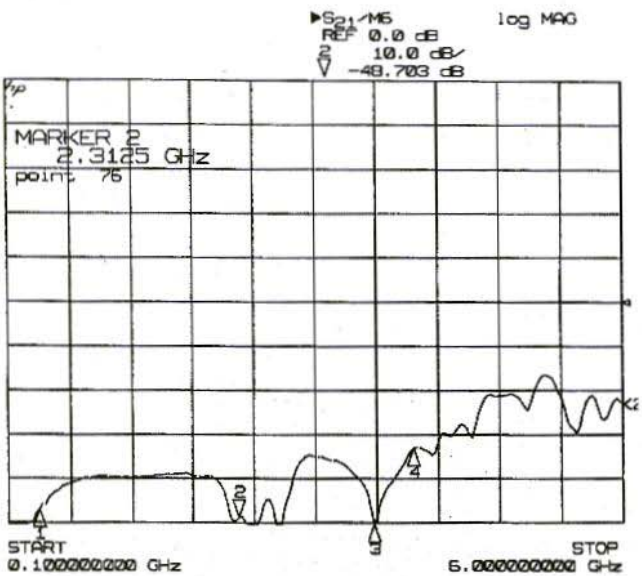

Fig.8: Measurement Diagram for Directivity Port 2 to 3:

400 MHz - 2.5 GHz ≥ 18dB,

400 MHz - 3.5 GHz ≥ 14dB

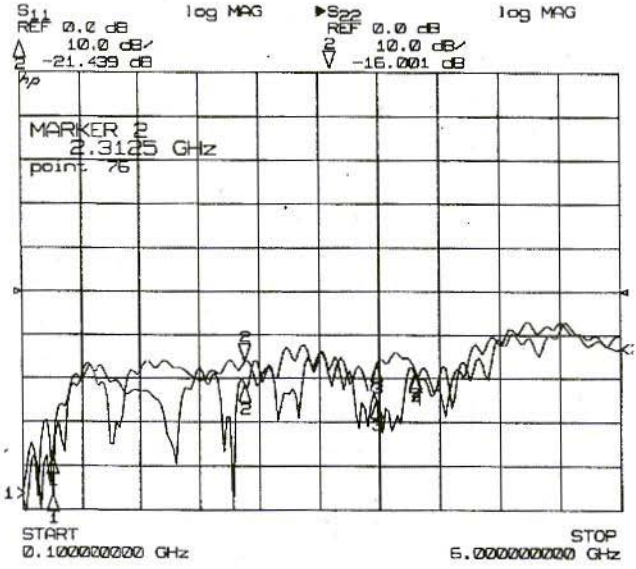

Fig.9:
Matching of Ports 1, 2 and 3;

400 MHz - 2.5 GHz
$R_L \geq 16dB$,

400 MHz - 3.5 GHz
$R_L \geq 13dB$

– The intervals of the coupler lines (centre of track in each case) are S1 = 175 mil, S2 = 140 mil, S3 = 120 mil, S4 = 100 mil and S5 = 85 mil > coupling gap: 119 mil, 84 mil, 64 mil, 44 mil, 29 mil.

The layout was printed onto film on a 1:1 scale using a laser printer and engraved using normal engraving equipment.

As regards sockets, an SMA construction with "pennants" was used on the prototype, and an SMA seal was used at port 4.

The assembly coupling is 21 ± 1dB (350 MHz to 3.5 GHz). The directivity is better than 20dB up to 2 GHz and better than 18dB up to 3.5 GHz.

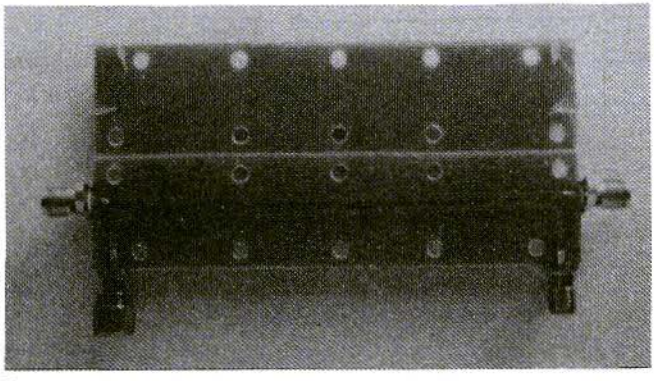

Fig.10:
Coupler made from 2 x 1.5 mm. Epoxy with SMA Sockets

6. SUMMARY

The directional coupler described above could certainly be developed further in relation to the matching and the directivity. Better sockets - e.g. SMA's - and an SMA seal resistance improve the results markedly.

I would like to thank K.Eichel, DL6SES, from the TSS company for support with Super-Compact, and DL1TR for measuring the prototype.

7. LITERATURE REFERENCES

[1] Harlan Howe, Jr.: Stripline Circuit Design (1974), Artech House

[2] Elements Library Super-Compact, Compact Software, USA

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